

REGENERATION CONTROLLER FOR EXHAUST PURIFICATION APPARATUS
OF INTERNAL COMBUSTION ENGINE

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FIELD OF THE INVENTION

The present invention relates to a regeneration controller for an exhaust purification apparatus of an internal combustion engine that eliminates particulate matter trapped in the exhaust purification apparatus by heating the exhaust purification apparatus.

BACKGROUND OF THE INVENTION

Japanese Laid-Open Patent Publication No. 2003-20930 describes a technique for burning particulate matter (PM) accumulated in a filter, which is arranged in an exhaust passage of a diesel engine, when the amount of PM accumulated in the filter exceeds a predetermined amount. The PM accumulated in the filter is burned by heating the filter and intermittently adjusting the air-fuel ratio to the lean side. In this prior art, the amount of PM accumulated in the filter is estimated by cyclically adding the amount of PM emitted from the engine and the amount of PM oxidized in the filter based on the driving state of the engine.

When the engine driving state is changing, the actual PM emission amount and the PM oxidation amount may not be the same and differ from each other. In particular, the estimated

PM accumulation amount may be less than the actual PM accumulation amount. When the actual accumulation amount is greater than the estimated accumulation amount, the elimination of the accumulated PM may be insufficient. If such insufficient elimination is repeated, an excessively large amount of PM may be accumulated. In such a case, a greater amount of PM than intended may be rapidly burned. As a result, the filter would become overheated. This would cause thermal deterioration of the filter.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a controller that minimizes the difference between the estimated accumulation amount and the actual accumulation amount of particulate matter, while appropriately eliminating the particulate matter accumulated in an exhaust purification apparatus.

One aspect of the present invention is a regeneration controller for regenerating an exhaust purification apparatus that is arranged in an exhaust passage for an internal combustion engine. The exhaust purification apparatus includes an upstream purification portion and a downstream purification portion. The regeneration controller includes a difference detector for detecting at least one of a difference in exhaust pressure, between a first location upstream from the exhaust purification apparatus and a second location downstream from the exhaust purification apparatus, and a difference in exhaust temperature, between a third location upstream from the downstream purification portion of the exhaust purification apparatus and a fourth location downstream from the third location. A calculation section calculates an estimated accumulation amount of particulate

matter in the exhaust purification apparatus. A heating control section heats the exhaust purification apparatus to eliminate the particulate matter from the exhaust purification apparatus when the estimated accumulation amount is greater than a reference accumulation amount. A correction control section corrects the estimated accumulation amount in accordance with the at least one difference, when the estimated accumulation amount falls within a correction determination reference range due to the heating and the at least one difference is greater than a correction reference value.

Another object of the present invention is a regeneration controller for regenerating an exhaust purification apparatus that is arranged in an exhaust passage for an internal combustion engine. The exhaust purification apparatus includes an upstream purification mechanism and a downstream purification mechanism that are arranged in the exhaust passage. The regeneration controller includes a difference detector for detecting at least one of a difference in exhaust pressure and a difference in exhaust temperature between an upstream location and a downstream location of the downstream purification mechanism. A calculation section calculates an estimated accumulation amount of particulate matter in the exhaust purification apparatus. A heating control section heats the exhaust purification apparatus to eliminate the particulate matter from the exhaust purification apparatus when the estimated accumulation amount is greater than a reference accumulation amount. A correction control section corrects the estimated accumulation amount, when the estimated accumulation amount falls within a correction determination reference range due to the heating and the at least one difference is greater than a correction reference value, in accordance with the at

least one difference.

Other aspects and advantages of the present invention will become apparent from the following description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention, together with objects and advantages thereof, may best be understood by reference to the following description of the presently preferred embodiments together with the accompanying drawings in which:

Fig. 1 is a schematic diagram of a control system for a vehicle diesel engine according to a first embodiment of the present invention;

Fig. 2 is a flowchart of a regeneration mode execution determination executed by the ECU shown in Fig. 1;

Fig. 3 is a flowchart of regeneration control executed by the ECU shown in Fig. 1;

Fig. 4 shows a correction reference value map MAP_dp;

Fig. 5 shows an addition correction amount map MAP_{add};

Figs. 6 and 7 are timing charts of the regeneration control in the first embodiment;

Fig. 8 is a flowchart of regeneration control according to a second embodiment of the present invention;

Fig. 9 shows an addition correction amount map MAP_{tad};

Figs. 10 and 11 are flowcharts of regeneration control according to a third embodiment of the present invention; and

Fig. 12 is a schematic diagram of an exhaust purification apparatus according to a third embodiment of the present invention.

DETAILED DESCRIPTION

A regeneration controller for an exhaust purification apparatus of an internal combustion engine according to a first embodiment of the present invention will now be discussed. Fig. 1 is a schematic diagram of a control system including the regeneration controller, which is applied to a vehicle diesel engine. The application of the regeneration controller of the present invention is not limited to a diesel engine. That is, the regeneration controller of the present invention is also applicable to a lean-burn gasoline engine.

A diesel engine 2 includes a plurality of cylinders including first to fourth cylinders #1, #2, #3, and #4. In each of the cylinders #1 to #4, a combustion chamber 4 is connected to a surge tank 12 via an intake port 8 and an intake manifold 10. Each intake port 8 is opened and closed by an intake valve 6. The surge tank 12 is connected to an intercooler 14 and a supercharger such as an exhaust turbocharger 16. Fresh air supplied via an air cleaner 18 is compressed by a compressor 16a of the exhaust turbocharger 16. The surge tank 12 has an EGR gas supply port 20a of an exhaust gas recirculation (EGR) passage 20. A throttle valve 22 is arranged in an intake passage 13 between the surge tank 12 and the intercooler 14. An intake air amount sensor 24 (intake air amount detector) and an intake air temperature sensor 26 are arranged between the compressor 16a and the air cleaner 18.

In each of the cylinders #1 to #4, the combustion chamber 4 is connected to an exhaust port 30 and an exhaust manifold 32. Each exhaust port 30 is opened and closed by an exhaust valve 28. An exhaust turbine 16b of the exhaust turbocharger 16 is arranged between the exhaust manifold 32

and the exhaust passage 34. The exhaust is sent into the exhaust turbine 16b from a position in the exhaust manifold 32 close to the fourth cylinder #4.

Three exhaust purification mechanisms, each accommodating an exhaust purification catalyst, namely, catalytic converters 36, 38, and 40, are arranged in the exhaust passage 34. The first catalytic converter 36, which is positioned the furthest upstream, accommodates a NOx storage reduction catalyst 36a. When the exhaust of the diesel engine 2, which is operating normally, is in an oxidation atmosphere (lean), NOx is stored in the NOx storage reduction catalyst 36a. When the exhaust is in a reduction atmosphere (stoichiometric or air-fuel ratio being lower than that the stoichiometric condition), the NOx stored in the NOx storage reduction catalyst 36a is reduced to NO, separated from the NOx storage reduction catalyst 26a, and further reduced using HC and CO. In this way, NOx is eliminated.

The second catalytic converter 38, which is arranged downstream from the first catalytic converter 36, accommodates a filter 38a having a monolithic structure. Walls of the filter 38a have pores that permit the passage of exhaust. The porous wall surface of the filter 38a is coated with a layer of a NOx storage reduction catalyst. The filter 38a functions as a base for the NOx storage reduction catalyst layer. The NOx storage reduction catalyst layer eliminates NOx in the same manner as the NOx storage reduction catalyst 36a. Particulate matter (PM) contained in the exhaust is accumulated in the wall of the filter 38a. The PM is first oxidized by active oxygen released when NOx is exposed in an oxidation atmosphere under a relatively high temperature. Then, the PM is entirely oxidized by the surrounding excess oxygen. In this way, not only NOx but also

PM is eliminated from the filter 38a. The first catalytic converter 36 is formed integrally with the second catalytic converter 38.

The third catalytic converter 40, which is positioned most downstream, accommodates an oxidation catalyst 40a for eliminating HC and CO through oxidation. A first exhaust temperature sensor 44 is arranged between the NOx storage reduction catalyst 36a and the filter 38a. Between the filter 38a and the oxidation catalyst 40a, a second exhaust temperature sensor 46 is arranged near the filter 38a, and an air-fuel ratio sensor 48 is arranged near the oxidation catalyst 40a.

The air-fuel ratio sensor 48 is, for example, a sensor using a solid electrolyte. The air-fuel ratio sensor 48 detects the air-fuel ratio of the exhaust based on exhaust components and generates a voltage signal, which is linearly proportional to the air-fuel ratio. The first exhaust temperature sensor 44 and the second exhaust temperature sensor 46 respectively detect exhaust temperatures th_{ci} and th_{co} at their respective locations.

A pressure difference sensor 50 is connected to a pipe connecting the upstream side and downstream side of the filter 38a. The pressure difference sensor 50 detects the pressure difference ΔP between the upstream and downstream sides of the filter 38a to detect the clogging degree of the filter 38a, that is, the degree of accumulation of PM in the filter 38a.

The exhaust manifold 32 has an EGR gas inlet 20b of the EGR passage 20 located near the first cylinder #1, or distant from the fourth cylinder #4 that sends exhaust into the

exhaust turbine 16b. An iron EGR catalyst 52 for reforming the EGR gas, a cooler 54 for cooling the EGR gas, and an EGR valve 56 are arranged in the EGR passage 20 in this order from the EGR gas inlet 20b. The EGR catalyst 52 also functions to prevent clogging of the cooler 54. The amount of EGR gas that is to be supplied again to the intake system via the EGR gas supply port 20a is adjusted according to the opening degree of the EGR valve 56.

A fuel injection valve 58 is arranged in each of the cylinders #1 to #4 and directly injects fuel into the corresponding combustion chamber 4. Each fuel injection valve 58 is connected to a common rail 60 via a fuel supply pipe 58a. A variable discharge amount fuel pump 62, which is electrically controlled, supplies high-pressure fuel into the common rail 60. The high-pressure fuel in the common rail 60 is distributed to the corresponding fuel injection valve 58 via each fuel supply pipe 58a. A fuel pressure sensor 64 detects the pressure of fuel in the common rail 60.

The fuel pump 62 supplies low-pressure fuel to a fuel adding valve 68 via a fuel supply pipe 66. The fuel adding valve 68 is arranged in an exhaust port 30 of the fourth cylinder #4 to inject fuel toward the exhaust turbine 16b. The fuel adding valve 68 adds fuel to the exhaust in a catalyst control mode.

An electronic control unit (ECU) 70 includes a digital computer system including a CPU, a ROM, a RAM, and drive circuits. The drive circuit drives various units. The ECU 70 is provided with detection signals from the intake air amount sensor 24, the intake air temperature sensor 26, the first exhaust temperature sensor 44, the second exhaust temperature sensor 46, the air-fuel ratio sensor 48, the pressure

difference sensor 50, an EGR opening degree sensor included in the EGR valve 56, a fuel pressure sensor 64, a throttle opening degree sensor 22a, an accelerator opening degree sensor 74, a coolant temperature sensor 76, an engine speed sensor 80, and a cylinder distinction sensor 82. The accelerator opening degree sensor 74 detects the depressed amount of an accelerator pedal 72 (accelerator opening degree ACCP). The coolant temperature sensor 76 detects the coolant temperature THW of the diesel engine 2. The engine speed sensor 80 detects the engine speed NE, or rotation speed of the crankshaft 78. The cylinder distinction sensor 82 detects the rotational phase of the crankshaft 78 or the rotational phase of an intake cam to distinguish cylinders.

The ECU 70 determines the driving state of the engine from these detection signals to control fuel injection (amount and timing) of the fuel injection valves 58 according to the driving state of the engine. The ECU 70 executes control for adjusting the opening degree of the EGR valve 56, adjusting the throttle opening degree with a motor 22b, and adjusting the discharge amount of the fuel pump 62. Further, the ECU 70 executes catalyst control including a regeneration mode, a sulfur components decomposition-release mode (hereinafter referred as a sulfur elimination mode), a NOx reduction mode, and a normal control mode. The catalyst control will be described later.

The ECU 70 executes a combustion mode selected from two combustion modes, namely, a normal combustion mode and a low temperature combustion mode, according to the driving state of the engine. In the low temperature combustion mode, the ECU 70 simultaneously reduces NOx and smoke by slowing the increase of the combustion temperature by using a large recirculation amount of exhaust based on an EGR valve opening

degree map for the low temperature combustion mode. The low temperature combustion mode is executed when the engine is in a range in which the engine load is low and the engine speed is low or intermediate. In the low temperature combustion mode, the ECU 70 executes air-fuel ratio feedback control including adjustment of a throttle opening degree TA based on the air-fuel ratio AF detected by the air-fuel ratio sensor 48. A combustion mode other than the low temperature combustion mode is the normal combustion mode. In the normal combustion mode, the ECU 70 executes normal EGR control (including control that involves no recirculation of the exhaust) based on an EGR valve opening degree map for the normal combustion mode.

The catalyst control will now be described.

In the regeneration mode, the ECU 70 particularly heats PM accumulated in the filter 38a of the second catalytic converter 38 when the estimated accumulation amount of PM in the exhaust purification catalyst reaches a regeneration reference value. The PM is heated to be oxidized and decomposed to generate CO_2 and H_2O and is released as CO_2 and H_2O . In the regeneration mode, the ECU 70 repeatedly adds fuel with the fuel adding valve 68 to heat (e.g., 600 to 700°C) the catalyst bed at an air-fuel ratio that is higher than the stoichiometric air-fuel ratio. The ECU 70 may further perform fuel injection (after injection) in each combustion chamber 4 with the corresponding fuel injection valve 58 during the power stroke or the exhaust stroke. The ECU 70 further executes burn-up heating by executing an intermittent fuel adding process under a specific condition, which will be described later. In the intermittent fuel adding process, the ECU 70 executes an air-fuel ratio lowering process between periods in which no fuel is added.

The air-fuel ratio lowering process lowers the air-fuel ratio to be the same as or slightly lower than the stoichiometric air-fuel ratio by intermittently adding fuel from the fuel adding valve 68. In this embodiment, the air-fuel ratio lowering process causes the air-fuel ratio to be slightly lower than the stoichiometric air-fuel ratio. In certain cases, the after injection with the fuel injection valves 58 and the intermittent fuel adding process may be performed in combination. In the regeneration mode, the PM clogging at the front surface of the NOx storage reduction catalyst 36a is eliminated and the PM accumulated in the filter 38a at an accumulation amount greater than the estimated accumulation amount is burned and reduced.

The sulfur elimination mode is executed when the NOx storage reduction catalyst 36a and the filter 38a are poisoned by sulfur components and their exhaust purification capacity such as NOx storage capacity is lowered. The sulfur elimination mode decomposes and releases sulfur components from the NOx storage reduction catalyst 36a and the filter 38a so that the NOx storage reduction catalyst 36a and the filter 38a are rid of sulfur components and restored from sulfur poisoning. In the sulfur elimination mode, the ECU 70 heats the catalyst bed (e.g., to 650°C) by repeatedly adding fuel from the fuel adding valve 68. The ECU 70 further executes an air-fuel ratio lowering process that lowers the air-fuel ratio to be the same as or slightly lower than the stoichiometric air-fuel ratio by intermittently adding fuel from the fuel adding valve 68. In the first embodiment, the air-fuel ratio lowering process causes the air-fuel ratio to be slightly lower than the stoichiometric air-fuel ratio. In the sulfur elimination mode, the after injection using the fuel injection valve 58 may also be executed. This process is similar to the intermittent fuel adding process executed

under a specific condition in the regeneration mode and also has the effect of burning up the PM.

In the NOx reduction mode, NOx occluded in the NOx storage reduction catalyst 36a and the filter 38a is reduced to N₂, CO₂, and H₂O, and is released as N₂, CO₂, and H₂O. In the NOx reduction mode, the ECU 70 intermittently adds fuel from the fuel adding valve 68 at relatively long time intervals so that the temperature of the catalyst bed is set relatively low (e.g., 250 to 500°C). At such a relatively low catalyst bed temperature, the air-fuel ratio is lowered to be the same as or slightly lower than the stoichiometric air-fuel ratio.

The catalyst control excluding the three catalyst control modes described above is the normal control mode. In the normal control mode, the ECU 70 does not perform the fuel addition with the fuel adding valve 68 and the after injection with the fuel injection valve 58.

The processing executed by the ECU 70 in the regeneration mode will now be discussed. The flowchart of Fig. 2 showing the regeneration mode execution determination and the flowchart of Fig. 3 showing the regeneration control are each executed as interrupts in predetermined time cycles. The result of the regeneration mode execution determination in Fig. 2 determines whether to start the regeneration control in Fig. 3.

The regeneration mode execution determination (Fig. 2) will first be described.

In step S102, the ECU 70 calculates the particulate matter emission amount P_{Me}, which is the total amount of PM

emitted from each combustion chamber 4 of the diesel engine 2 during one control cycle in Fig. 2. In this embodiment, the ECU 70 calculates the particulate matter emission amount PMe by referring to a map, which is generated in advance through experiments. The map associates the emission amount with, for example, the engine speed NE and with the engine load (e.g., the fuel injection amount of the fuel injection valve 58). The ECU 70 calculates the particulate matter emission amount PMe from the engine speed NE and the engine load.

In step S104, the ECU 70 calculates the oxidation amount PMc of PM that is accumulated or trapped in the filter 38a. The oxidation amount PMc is the amount of the trapped PM that is eliminated through oxidation during one control cycle of this process. In the first embodiment, the ECU 70 calculates the oxidation amount PMc by referring to a map, which is generated in advance through experiments. The map associates the oxidation amount with the catalyst bed temperature of the filter 38a (e.g., the exhaust temperature $thco$ detected by the second exhaust temperature sensor 46) and with an intake air amount GA . The ECU 70 calculates the oxidation amount PMc from the exhaust temperature $thco$ and the intake air amount GA .

In step S106, the ECU 70 calculates an estimated PM accumulation amount $PMsm$ using expression 1.

$$PMsm \leftarrow \text{Max}[PMsm + PMe - PMc, 0] \quad (1)$$

In expression 1, the estimated accumulation amount $PMsm$ in the right side is the value calculated in the previous cycle of this process. Max represents an operator for extracting the maximum value of the values in the parentheses. For example, when $PMsm + PMe - PMc$ is a positive

value, the resulting value of $PM_{sm} + PM_e - PM_c$ is entered as the estimated accumulation amount PM_{sm} at the left side of the expression. When $PM_{sm} + PM_e - PM_c$ is a negative value, zero (grams) is entered as the estimated accumulation amount PM_{sm} at the left side of the expression.

In step S108, the ECU 70 checks whether the estimated accumulation amount PM_{sm} is greater than or equal to a regeneration reference value PM_{start} (corresponding to a reference accumulation amount) and determines whether to start the regeneration mode. When PM_{sm} is less than PM_{start} (NO in step S108), the ECU 70 temporarily terminates this process. The state in which PM_{sm} is less than PM_{start} corresponds to a state before timing t_0 shown in the timing chart of Fig. 6.

When the state in which PM_e is greater than PM_c continues due to the driving state of the diesel engine 2, steps S102, S104, and S106 is repeated. This gradually increases the estimated accumulation amount PM_{sm} . However, as long as PM_{sm} is less than PM_{start} (NO in step S108), the ECU 70 temporarily terminates this process.

When the estimated accumulation amount PM_{sm} increases and satisfies $PM_{sm} \geq PM_{start}$ (YES in step S108), the ECU 70 determines whether heating for PM elimination in the sulfur elimination mode has stopped. When the PM elimination heating in the sulfur elimination mode has stopped (NO in step S110), the ECU 70 temporarily terminates this process. When the PM elimination heating in the sulfur elimination mode is being performed (YES in step S110), the ECU 70 starts the regeneration control (step S112, t_0 in Fig. 6). In this case, the regeneration control shown in Fig. 3 is executed cyclically.

The regeneration control will now be described with reference to Fig. 3. The ECU 70 executes the regeneration control after executing the regeneration mode execution determination in Fig. 2. Thus, the regeneration control is executed in the same cycle as the regeneration mode execution determination.

In step S122, the ECU 70 determines whether the estimated accumulation amount PMsm calculated in the previous cycle is within a correction determination reference range (less than or equal to a maximum value BUpm of the correction determination reference range). As shown in Fig. 6, the maximum value BUpm is much smaller than the regeneration reference value PMstart and slightly greater than a termination determination value PMend (e.g., 0 grams).

When PMsm is greater than BUpm (NO in step S122, t0 to t1 in Fig. 6), the ECU 70 sets (instructs) initiation of the PM elimination heating in step S146 and temporarily terminates this process. In the PM elimination heating, the fuel adding valve 68 repeatedly adds fuel in the manner described above. This exposes the catalyst to an atmosphere in which the air-fuel ratio is higher than the stoichiometric air-fuel ratio and raises the catalyst bed temperature (exhaust temperature thci) (e.g., 600 to 700°C). Then, the particulate matter emission amount PMe becomes less than the oxidation amount PMc, and the estimated accumulation amount PMsm decreases gradually.

As long as PMsm is greater than BUpm (NO in step S122), the process for eliminating PM by the fuel addition described above is continued.

The estimated accumulation amount PM_{sm} gradually decreases and approaches the termination determination value PM_{end} . When the estimated accumulation amount PM_{sm} decreases and satisfies $PM_{sm} \leq BU_{pm}$ (YES in step S122), the ECU 70 determines whether a mode other than the sulfur elimination mode is presently being executed and whether a mode other than the sulfur elimination mode has been requested (step S124).

When the sulfur elimination mode is being executed or when the sulfur elimination mode has been requested (NO in step S124), the ECU 70 stops the PM elimination heating (step S138) and temporarily terminates this process. The PM elimination heating is stopped because a processing similar to the burn-up heating is performed in the sulfur elimination mode.

When a mode other than the sulfur elimination mode is being executed and the sulfur elimination mode is not requested (YES in step S124), the ECU 70 refers to a correction reference value map MAP_{dp} shown in Fig. 4 and determines a correction reference value D_p that corresponds to the intake air amount GA (step S126). The ECU 70 determines whether the ratio $\Delta P/GA$ of the pressure difference ΔP between the upstream and downstream sides of the filter 38a to the intake air amount GA is greater than or equal to a correction reference value D_p (step S128). The ratio $\Delta P/GA$ corresponds to an exhaust pressure difference. Accordingly, the reference value D_p is used as a minimum value of the ratio $\Delta P/GA$. The accuracy for determining clogging of the filter 38a is ensured by determining the reference value D_p .

It is preferred that the ratio of the pressure difference ΔP to an exhaust flow amount be used instead of

the ratio $\Delta P/GA$ to accurately reflect the actual driving state. However, the intake air amount GA is directly proportional to the exhaust flow amount. Thus, the use of the ratio $\Delta P/GA$ does not affect control accuracy.

Instead of comparing the ratio $\Delta P/GA$ with the value Dp , the pressure difference ΔP may be compared with a correction reference value (e.g., $Dp*GA$) that is set larger in accordance with the exhaust flow amount (or the intake air amount GA). In this case, the pressure difference ΔP corresponds to the exhaust pressure difference.

When $\Delta P/GA$ is less than Dp (NO in step S128), the filter 38a is not clogged with PM, and the estimated accumulation amount PM_{sm} is not deviated from the actual accumulation amount. In this case, the ECU 70 determines whether the estimated accumulation amount PM_{sm} is less than or equal to the termination determination value PM_{end} in step S140. In the initial stage of the regeneration control, PM_{sm} is less than PM_{end} (NO in step S140). Thus, the PM elimination heating is continued (step S146). In this case, as shown in Fig. 6, the estimated accumulation amount PM_{sm} continues to decrease gradually after timing $t1$ in accordance with the calculation using the expression 1.

When the state in which $\Delta P/GA$ is less than Dp continues (NO in step S128) and the estimated accumulation amount PM_{sm} decreases and satisfies $PM_{sm} \leq PM_{end}$ (0 grams) (YES in step S140, $t2$ in Fig. 6), the ECU 70 stops the PM elimination heating (step S142) and ends the regeneration mode (step S144). Then, the ECU 70 temporarily terminates this process. This completes the elimination of PM mainly trapped in the filter 38a. When the estimated accumulation amount PM_{sm} increases to satisfy $PM_{sm} \geq PM_{start}$ again (YES in step S108 of Fig. 2), the regeneration control is started again in the

manner described above (step S112) unless the regeneration control is stopped by the sulfur elimination mode (YES in step S110).

The following describes a case in which the filter 38a is clogged with PM and the estimated accumulation amount PM_{sm} is deviated from the actual accumulation amount. In this case, the ratio $\Delta P/GA$ becomes greater than or equal to the correction reference value D_p (YES in step S128) after the determination in step S122 results in YES and the determination in step S124 results in YES.

In step S130, the ECU 70 determines whether the number of times the determination in step S128 results in YES, that is, the number of times the ratio $\Delta P/GA$ is consecutively determined as greater than or equal to the value D_p is less than or equal to a stop determination number N_p (e.g., two). For example, when the determination number is smaller than the stop determination number N_p such as when the determination in step S130 has been executed for the first time (YES in step S130), the ECU 70 refers to an addition correction amount map MAP_{add} shown in Fig. 5 and determines an increase correction amount PM_{add} corresponding to the ratio $\Delta P/GA$ (step S132).

The ratio $\Delta P/GA$ reflects the deviation of the estimated accumulation amount PM_{sm} from the actual accumulation amount. The addition correction map MAP_{add} shows addition correction amounts PM_{add} in correspondence with the ratio $\Delta P/GA$, or in accordance with the above-mentioned deviation. The relationship between the ratio $\Delta P/GA$ and the addition correction amount PM_{add} is determined through experiments.

The ECU 70 obtains or corrects the estimated

accumulation amount PM_{sm} using expression (2).

$$PM_{sm} \leftarrow PM_{sm} + PM_{add} \quad (2)$$

In this case, the estimated accumulation amount PM_{sm} is increased to a value close to or equal to the actual accumulation amount (t_{11}).

In step S136, the ECU 70 switches from the PM elimination heating to the burn-up heating and temporarily terminates this process. When burn-up heating is started, the PM clogging at the front surface of the NOx storage reduction catalyst 36a is eliminated, and the amount of PM accumulated in the filter 38a that is greater than the estimated accumulation amount PM_{sm} is burned up. This reduces the deviation of the estimated accumulation amount PM_{sm} from the actual accumulation amount. The estimated accumulation amount PM_{sm} is once lowered to be less than or equal to the maximum value BU_{pm} , which is slightly greater than the termination determination value PM_{end} . Thus, even if the estimated accumulation amount PM_{sm} deviates from the actual accumulation amount, the burn-up heating avoids a case in which a large amount of PM is burned rapidly.

In a period in which PM_{sm} is greater than BU_{pm} (NO in step S122), the burn-up type PM elimination heating is performed (step S146). When $PM_{sm} \leq BU_{pm}$ is satisfied again (YES in step S122, t_{12} in Fig. 7) and $\Delta P/GA$ is less than D_p (NO in step S128) and PM_{sm} is greater than PM_{end} (NO in step S140), the PM elimination heating is continued as indicated by the solid line in Fig. 7 (step S146). When $PM_{sm} \leq PM_{end}$ is satisfied (YES in step S140), the PM elimination heating is stopped (step S142), and the regeneration mode is completed (step S144, t_{13} in Fig. 7).

When $\Delta P/GA \geq Dp$ is satisfied (YES in step S128), the ECU 70 determines whether the determination number in step S128 is less than or equal to the stop determination number Np (two) (step S130). For example, when the determination in step S128 is executed for the second time (YES in step S130), the ECU 70 determines again the addition correction amount $PMadd$ based on the ratio $\Delta P/GA$ (step S132) and corrects the estimated accumulation amount $PMsm$ with the updated addition correction amount $PMadd$ (step S134). Thus, as indicated by the broken line in Fig. 7, the estimated accumulation amount $PMsm$ increases again to a value greater than the maximum value $BUpm$ (t12).

The ECU 70 continues the burn-up heating (step S136), and temporarily terminates this process. The continued burn-up heating further reduces the deviation of the estimated accumulation amount $PMsm$ from the actual accumulation amount.

In a period in which $PMsm$ is greater than $BUpm$ (NO in step S122), the ECU 70 continues the burn-up heating (step S146). When $PMsm \geq BUpm$ is satisfied again (YES in step S122, t14 in Fig. 7), and when $\Delta P/GA$ is less than Dp (NO in step S128) and $PMsm$ is greater than $PMend$ (NO in step S140), the ECU 70 continues the burn-up type PM elimination heating (step S146). When $PMsm \leq PMend$ is satisfied (YES in step S140, t15 in Fig. 7), the ECU 70 stops the PM elimination heating (step S142) and completes the regeneration mode (step S144).

When $\Delta P/GA \geq Dp$ is satisfied (YES in step S128, t13), the determination relating to the ratio $\Delta P/GA$ has been executed for the third time (NO in step S130). In this case, the ECU 70 executes the same processing as the processing

executed when $\Delta P/GA$ is less than Dp . When $PM_{sm} \leq PM_{end}$ is satisfied as indicated by the broken line in Fig. 7 (YES in step S140, t15 in Fig. 7), the ECU 70 stops the PM elimination heating (step S142), and completes the regeneration mode (step S144).

The pressure difference sensor 50 and the intake air amount sensor 24 serve as a difference detector. The ECU 70 executing steps S122 to S134 functions as a correction control section for the estimated accumulation amount.

The first embodiment has the advantages described below.

(a) The flow resistance of the exhaust increases and the exhaust pressure difference $\Delta P/GA$ between the upstream and downstream sides of the filter 38a increases as the degree of the PM clogging in the filter 38a in the second catalytic converter 38 increases. When the estimated accumulation amount PM_{sm} does not deviate from the actual accumulation amount, the exhaust pressure difference $\Delta P/GA$ corresponds to the estimated accumulation amount PM_{sm} . Accordingly, the estimated accumulation amount PM_{sm} is accurate if the exhaust pressure difference $\Delta P/GA$ detected by the pressure difference sensor 50 is a value corresponding to the correction determination reference range ($\leq BU_{pm}$) when the estimated accumulation amount PM_{sm} falls within the correction determination reference range.

When the exhaust pressure difference $\Delta P/GA$ is greater than the correction determination reference range, the actual accumulation amount is greater than the estimated accumulation amount PM_{sm} . If such state continues, the regeneration mode is completed even though there is residual PM. When such residual PM elimination is accumulated, the

deviation of the estimated accumulation amount PM_{sm} from the actual accumulation amount gradually increases. This would lead to an amount of PM greater than intended to be burned rapidly. As a result, the filter 38a may become excessively heated and cause thermal deterioration of the filter 38a.

In the first embodiment, the ECU 70 compares the ratio $\Delta P/GA$ with the correction reference value D_p when $PM_{sm} \leq BU_{pm}$ is satisfied to determine whether the estimated accumulation amount PM_{sm} is deviated from the actual accumulation amount. When $\Delta P/GA \geq D_p$ is satisfied, the ECU 70 refers to the addition correction amount map MAP_{add} to determine the addition correction amount PM_{add} corresponding to the ratio $\Delta P/GA$ and corrects the estimated accumulation amount PM_{sm} with the addition correction amount PM_{add} . As the ratio $\Delta P/GA$ increases, the addition correction amount PM_{add} increases. This causes the estimated accumulation amount PM_{sm} to approach or be the same as the actual accumulation amount.

In this way, the difference between the estimated accumulation amount PM_{sm} and the actual accumulation amount is minimized so that the PM accumulated in the filter 38a is appropriately eliminated. This prevents a large amount of PM from being rapidly burned.

(b) Normally, in accordance with the flow amount of exhaust, the flow uniformity of the exhaust flow changes and the accuracy of sensors for detecting exhaust pressure and exhaust temperature decreases. Therefore, it is preferable that the correction reference value be set in accordance with the exhaust flow amount. In the first embodiment, the ECU 70 refers to the correction reference map MAP_{dp} shown in Fig. 4 to determine the correction reference value D_p . The correction reference value D_p in the correction reference

value map MAPdp is set so that it becomes smaller as the intake air amount GA increases. As the intake air amount GA increases, the exhaust flow amount increases. This improves the flow uniformity of the exhaust flow amount. Thus, the correction reference value Dp decreases as the intake air amount GA increases, and the correction reference value Dp increases as the intake air amount GA decreases. This determines the timing for correcting the estimated accumulation amount PMsm with high accuracy and thus obtains an addition correction amount PMadd with higher accuracy. Accordingly, the estimated accumulation amount PMsm is corrected with higher accuracy, and the deviation of the estimated accumulation amount PMsm from the actual accumulation amount is minimized with further accuracy.

(c) The intake air amount GA detected by the intake air amount sensor 24 is used in lieu of the exhaust flow amount. Thus, the appropriate correction reference value Dp is easily set, and a highly accurate addition correction amount PMadd is easily obtained at a highly accurate timing.

(d) The correction determination reference range defined using the maximum value BUpm is set in a range defined by the estimated accumulation amount PMsm immediately before the regeneration mode is completed. The actual PM accumulation amount is sufficiently reduced by executing normal heating for PM elimination. Thus, even when burn-up heating is performed to burn up all of the PM at the same time, a state in which the burn-up heating rapidly burns a large amount of PM is avoided. Thus, even with such special heating, the filter 38a is not excessively heated and thermal deterioration of the filter 38a does not occur. Hence, the accumulated particulate matter is appropriately eliminated.

(e) When the corrected estimated accumulation amount PM_{sm} falls within the correction determination reference range again and $\Delta P/GA \geq D_p$ is satisfied, the ECU 70 repeats the correction of the estimated accumulation amount PM_{sm} . Thus, even when compensation for the deviation of the estimated accumulation amount PM_{sm} in the previous cycle from the actual accumulation amount is insufficient, repeated correction of the estimated accumulation amount PM_{sm} almost completely eliminates the deviation of the estimated accumulation amount PM_{sm} from the actual accumulation amount.

(f) The presence of non-combustible materials, such as ash, may cause a state in which $\Delta P/GA \geq D_p$ is satisfied to continue. In this case, repeatedly correcting the estimated accumulation amount PM_{sm} to extend the regeneration mode may lower fuel efficiency. Thus, the ECU 70 limits the number of times the estimated accumulation amount PM_{sm} is corrected to prevent the fuel efficiency from decreasing. In this embodiment, the stop determination number N_p is set as two so that the correction of the estimated accumulation amount PM_{sm} is not executed three consecutive times.

(g) The sulfur elimination mode has the same effect as the effect of the burn-up heating. Thus, even when the estimated accumulation amount PM_{sm} deviates from the actual accumulation amount, the deviation is reduced or eliminated in the sulfur elimination mode. Thus, the ECU 70 does not execute the correction of the estimated accumulation amount PM_{sm} in the sulfur elimination mode. In this way, the regeneration mode, particularly the burn-up heating, is not often executed to prevent the fuel efficiency from decreasing.

Regeneration control for an exhaust purification

apparatus of an internal combustion engine according to a second embodiment of the present invention will now be described with reference to Fig. 8.

In the second embodiment, the exhaust temperature difference ΔTHC ($\text{thco} - \text{thci}$) between the upstream and downstream sides of the filter 38a, which corresponds to a downstream exhaust purification mechanism, is used in lieu of the exhaust pressure difference $\Delta\text{P/GA}$. That is, the ECU 70 determines whether ΔTHC is greater than or equal to the correction reference value Dth . The correction reference value Dth is a value between, for example, 200 to 300°C. Steps S125, S127, S129, and S131 of Fig. 8 respectively replace steps S126, S128, S130, and S132 of Fig. 3. The other parts are the same as the first embodiment.

When the determination of step S124 results in YES, the ECU 70 obtains the exhaust temperature difference ΔTHC in accordance with expression 3.

$$\Delta\text{THC} \leftarrow \text{thco} - \text{thci} \quad (3)$$

The ECU 70 determines whether the exhaust temperature difference ΔTHC is greater than or equal to the correction reference value Dth (step S127). When ΔTHC is less than Dth (NO in step S127) and PMsm is greater than PMend (NO in step S140), the ECU 70 continues the PM elimination heating (step S146). When $\text{PMsm} \leq \text{PMend}$ is satisfied (YES in step S140), the ECU 70 stops PM elimination heating (step S142) and ends the PM regeneration control mode (step S144). During these steps, PMsm changes as shown by the timing chart of Fig. 6.

When $\Delta\text{THC} \geq \text{Dth}$ is satisfied (YES in step S127), the ECU 70 checks whether the number of times the determination of step S127 resulted in YES during repeating the present PM

elimination heating is less than or equal to a stop determination number N_p (e.g., two) (step S129). For example, when step S127 is performed the first time, the ECU 70 determines the result of S129 as YES. In this case, the ECU 70 refers to the addition correction amount map MAP_{tad} shown in Fig. 9 to determine the addition correction amount PM_{aad} corresponding to the exhaust temperature difference ΔTHC (step S131).

When clogging of the front surface of the NO_x storage reduction catalyst 36a deviates the estimated accumulation amount PM_{sm} from the actual accumulation amount, the fuel added by the fuel adding valve 68 to perform PM elimination heating is hardly burned when passing through the NO_x storage reduction catalyst 36a and burned in a concentrated manner at the filter 38a. This increases the exhaust temperature difference ΔTHC in comparison to when the front surface of the NO_x storage reduction catalyst 36a is not clogged. In other words, the exhaust temperature difference ΔTHC reflects the deviation of the estimated accumulation amount PM_{sm} from the actual accumulation amount that is caused by the clogging of the front surface of the NO_x storage reduction catalyst 36a. The addition correction amount map MAP_{tad} stores the addition correction amount PM_{add} corresponding to the exhaust temperature difference ΔTHC . The level of deviation becomes greater as the exhaust temperature difference ΔTHC increases. Thus, the addition correction amount PM_{add} increases as the exhaust temperature difference ΔTHC increases. The association of the exhaust temperature difference ΔTHC with the addition correction amount PM_{add} is obtained through experiments.

The ECU 70 uses the addition correction amount PM_{add} to correct the predicted accumulation amount PM_{sm} in accordance

with expression 2 (step S134). This increases the estimated accumulation amount PM_{sm} to approach or become equal to the actual accumulation amount as shown in the timing chart of Fig. 7.

The ECU 70 switches from PM elimination heating to burn-up heating (step S136). Even if the estimated accumulation amount PM_{sm} is deviated from the actual accumulation amount when starting burn-up heating, the estimated accumulation amount PM_{sm} is less than or equal to the maximum value BU_{pm} , which is slightly greater than the termination determination value PM_{end} . Accordingly, even if burn-up heating is performed, a large amount of PM is not rapidly burned. Thus, the filter 38a is not overheated.

During the period in which PM_{sm} is greater than BU_{pm} (NO in step S122), the ECU 70 eliminates PM by performing burn-up heating (step S146). When $PM_{sm} \leq BU_{pm}$ is satisfied again (YES in step S122) and the determination of step S124 is YES, the ECU 70 calculates the exhaust temperature difference ΔTHC (step S125). If ΔTHC is less than the correction reference value D_{th} (NO in step S127) and PM_{sm} is greater than PM_{end} (NO in step S140), the ECU 70 continues PM elimination heating (step S146, solid line in Fig. 7). If $PM_{sm} \leq PM_{end}$ is satisfied (YES in step S140), the ECU 70 stops PM elimination heating (step S142) and ends the PM regeneration control mode (step S144).

When $\Delta THC \geq D_{th}$ is satisfied again (YES in step S127), the ECU 70 checks whether the number of times the determination of step S127 results in YES is less than or equal to the stop determination number N_p (two) (step S129). Since the present determination number is two, the ECU 70 calculates the addition correction amount PM_{add} again based

on ΔTHC (step S131), updates the addition correction amount PMadd , and corrects the estimated accumulation amount PMsm again with the updated addition correction amount PMadd (step S134). As shown by the broken line in Fig. 7, this increases the estimated accumulation amount PMsm again to a value greater than the maximum value BUpm of the correction determination reference range.

The ECU 70 continues burn-up heating (step S136) and temporarily terminates this process. The continuation of burn-up heating further eliminates the deviation of the estimated accumulation amount PMsm and the actual accumulation amount.

During the period in which PMsm is greater than BUpm (NO in step S122), the ECU 70 continues burn-up heating (step S146). Even if $\text{PMsm} \leq \text{BUpm}$ is satisfied again (YES in step S122), as long as $\Delta\text{THC} \geq \text{Dth}$ is satisfied (YES in step S127), the ECU 70 determines the result of step S129 as NO. Even if $\Delta\text{THC} \geq \text{Dth}$ is satisfied or ΔTHC is less than Dth , the ECU 70 proceeds to step S140.

If burn-up heating continues and $\text{PMsm} \leq \text{PMend}$ is satisfied (YES in step S140), the ECU 70 stops PM elimination heating (step S142) and ends the PM regeneration control mode (step S144).

The first exhaust temperature sensor 44 and the second exhaust temperature sensor 46 serve as a difference detector. The ECU 70 executing steps S122 to S134 of Fig. 8 functions as a correction control section for correcting the estimated accumulation amount.

The second embodiment has the advantages described

below.

(a) When the NOx storage reduction catalyst 36a (upstream exhaust purification mechanism) is clogged with PM before the filter 38a is clogged with PM, the exhaust passes through only a limited portion of the NOx storage reduction catalyst 36a during the regeneration control. Thus, the reaction heat of the NOx storage reduction catalyst 36a is insufficient, and reaction heat is unevenly generated in the downstream filter 38a.

Accordingly, in the second embodiment, the exhaust temperature difference $th_{co}-th_{ci}$ between the upstream and downstream sides of the filter 38a is used in lieu of the exhaust pressure difference $\Delta P/GA$. The ECU 70 corrects the estimated accumulation amount PM_{sm} when the temperature difference is greater than or equal to the correction reference value D_{th} . This causes the estimated accumulation amount PM_{sm} to approach or to be the same as the actual accumulation amount.

In this way, the difference between the estimated accumulation amount PM_{sm} and the actual accumulation amount is minimized so that the accumulated PM is appropriately eliminated. This prevents rapid burning of a large amount of PM.

(b) The second embodiment also has advantages (d) to (g) described in the first embodiment.

Regeneration control for an exhaust purification apparatus of an internal combustion engine according to a third embodiment of the present invention will now be discussed.

In the third embodiment, the flowcharts of Figs. 10 and 11 are performed in lieu of the flowchart of Fig. 3. The flowcharts of Figs. 10 and 11 are obtained by combining the flowcharts of Figs. 3 and 8. That is, when either the determination of the exhaust pressure difference $\Delta P/GA$ (step S128) or the determination of the exhaust temperature difference ΔTHC (step S127) results in YES, steps S150, S152, S131, S132, S134, and S136 are performed. Refer to Fig. 3 or 8 with regard to the other steps.

When $\Delta P/GA \geq Dp$ is satisfied (YES in step S128) or $\Delta THC \geq Dth$ (YES in step S127) is satisfied, the ECU 70 determines whether the number of times the determinations of steps S127 and S128 resulted in YES is less than or equal to the stop determination number Np (step S150).

If the number of YES determinations is less than or equal to Np (YES in step S150), the ECU 70 checks whether the present step S150 resulted from the YES determination of S128 (step S152). If the present step S150 resulted from the YES determination of step S128 (YES in step S152), the ECU 70 refers to the addition correction map $MAPadd$ of Fig. 5 and determines the addition correction amount $PMadd$ corresponding to the exhaust pressure difference $\Delta P/GA$ (step S132). If the present step S150 resulted from the NO determination of step S128 and the YES determination of step S127 (NO in step S152), the ECU 70 refers to the addition correction map $MAPtad$ of Fig. 9 and determines the addition correction amount $PMadd$ corresponding to the exhaust temperature difference ΔTHC (step S131).

The ECU 70 corrects the estimated accumulation amount $PMsm$ in accordance with expression 2 with the addition

correction amount PMadd (step S134). This increases the estimated accumulation amount PMsm to approach or become equal to the actual accumulation amount.

The ECU 70 switches from PM elimination heating to burn-up heating after correcting the estimated accumulation amount (step S136) and temporarily terminates this process. The burn-up heating eliminates the PM clogging the front surface of the NOx storage reduction catalyst 36a, burns up the large amount of accumulated PM in the filter 38a that is greater than the estimated accumulation amount PMsm, and gradually reduces the deviation between the estimate accumulation amount PMsm and the actual accumulation amount PMsm. Even if the estimated accumulation amount PMsm is deviated from the actual accumulation amount when starting burn-up heating, the estimated accumulation amount PMsm is less than or equal to the maximum value BUpm of the correction determination reference range, which is slightly greater than the termination determination value PMend. Thus, burn-up heating does not rapidly burn a large amount of PM, and the filter 38a is not overheated.

The pressure difference sensor 50, the intake air amount sensor 24, the first exhaust temperature sensor 44, and the second exhaust temperature sensor 46 serve as a difference detector. The ECU 70 executing the regeneration control (Figs. 10 and 11) in steps S122, S124, S125, S126, S128, S150, S152, S131, and S132 functions as a correction control section.

The third embodiment has the advantages described below.

(a) The advantages described in the first and second embodiments are obtained. In particular, in addition to the exhaust pressure difference $\Delta P/GA$ between the upstream and

downstream sides of the filter 38a, the exhaust temperature difference ΔTHC between the upstream and downstream sides of the filter 38a is used. Thus, the difference between the estimated accumulation amount PM_{sm} and the actual accumulation amount is minimized so that the accumulated PM is appropriately eliminated. This reliably prevents rapid burning of a large amount of PM.

A regeneration controller for an exhaust purification apparatus of an internal combustion engine according to a fourth embodiment of the present invention will now be described.

In the fourth embodiment, referring to Fig. 12, a single filter 138a having a base coated with a layer of NOx storage reduction catalyst is used instead of the two catalytic converters described in the first embodiment, namely, the first catalytic converter and the second catalytic converter. A pressure difference sensor 150 detects the pressure difference ΔP between the upstream and downstream sides of the filter 138a. A first exhaust temperature sensor 144 detects the temperature (exhaust temperature thci) of the exhaust within the filter 138a. A second exhaust temperature sensor 46, an air-fuel ratio sensor 48, a third catalytic converter 40, and an oxidation catalyst 40a are identical to the corresponding components in the first embodiment, and are given the same reference numerals as those components.

The pressure difference sensor 150 detects the exhaust pressure difference $\Delta P/\text{GA}$ between the upstream and downstream sides of the exhaust purification apparatus. The first exhaust temperature sensor 144 detects the temperature of the exhaust in the filter 138a. The second exhaust temperature sensor 46 detects the temperature of the exhaust in the

vicinity of the outlet of the filter 138a. Accordingly, the first and second exhaust temperature sensors 144 and 46 detect the exhaust temperature difference $\Delta THC(thco-thci)$ at a relatively downstream portion of the exhaust purification apparatus.

The regeneration mode execution determination and the regeneration control described in one of the first to third embodiments are executed.

The fourth embodiment has the advantages described below.

(a) The catalyst arrangement according to the fourth embodiment also minimizes the difference between the estimated accumulation amount PM_{sm} and the actual accumulation amount so that the accumulated PM is appropriately eliminated. This prevents a large amount of PM from being rapidly burned.

It should be apparent to those skilled in the art that the present invention may be embodied in many other specific forms without departing from the spirit or scope of the invention. Particularly, it should be understood that the present invention may be embodied in the following forms.

(1) In the above embodiments, burn-up heating is performed when the determination relating to the exhaust pressure difference $\Delta P/GA$ or the determination relating to the exhaust temperature difference ΔTHC results in YES. However, normal PM elimination heating may be continued instead of switching to such special heating.

(2) The maximum value BU_{pm} in the above embodiments may

be the same value as the termination determination value PMend.

(3) In the above embodiments, the exhaust flow amount may be calculated from a driving state of the diesel engine 2, for example, from the engine speed NE and the fuel injection amount using a map instead of detecting the intake air amount GA using the intake air amount sensor 24. The ΔP /exhaust flow amount may be used as the exhaust pressure difference in various processing. Further, the correction reference value map MAPdp may be generated based on the exhaust flow amount.

The present examples and embodiments are to be considered as illustrative and not restrictive, and the invention is not to be limited to the details given herein, but may be modified within the scope and equivalence of the appended claims.